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STRENGTH AND DEFORMATION PROPERTIES OF VARIOUS ROCKS FROM THE SPRINGHILL COAL MINE, NOVA SCOTIA

Marc Bétournay

Rock Mechanics Laboratory

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by

Marc Bétournay*

ABSTRACT

Originating from the Springhill Mine, Nova Scotia, four distinct rock types from eight lithological units were subjected to multiple failure state tests. The mudstones, tested moist, displayed various strengths depending on the number of fissile discontinuities present in the sample before testing; failure was in a blocky fashion using these discontinuities. The sandstones, containing varying amounts of coal, from final units show a difference in strength; the influence of the coal on the failure mode depended on the orientation of the coal and its concentration. The strength and failure mode of the siltstones (tested moist) depended on the clay vs. silt grain size distribution. The coal sample failed at low strength with high displacements due to dislocations of weak planes.

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*Physical Scientist, Mine Evaluation Group, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

PROPRIÉTÉS DE RÉSISTANCE ET DE DÉFORMATION DE DIFFÉRENTES ROCHES DE LA HOUILLÈRE DE SPRINGHILL EN NOUVELLE-ÉCOSSE

par

Marc Bétournay*

RÉSUMÉ

On a soumis à plusieurs essais de rupture quatre échantillons de roche distincts provenant de huit unités lithologiques de la houillère de Springhill en Nouvelle-Écosse. Lors d'un essai par voie humide, la pelite a montré différentes formes de résistance selon le nombre de discontinuités fissiles présentes avant l'essai; la rupture s'est manifestée en blocs le long des discontinuités. Le grès des dernières unités qui contenait des quantités variables de charbon a montré des variations au niveau de la résistance; l'effet du charbon sur le mode de rupture du grès dépendait de l'orientation du charbon et de sa concentration. La résistance et le mode de rupture de l'aleurolite (essai par voie humide) était fonction de la distribution et de la taille du grain silteux par rapport à la teneur en argile de l'aleurolite. La rupture à faible résistance de l'échantillon de charbon s'est produite avec des déplacements importants causés par la dislocation des plans faibles.

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*Chercheurs en sciences physiques, Groupe d'évaluation des mines, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

CONTENTS

	Page
ABSTRACT	i
RÉSUMÉ	ii
INTRODUCTION	1
Specimen Descriptions	1
Experimental Set-up	2
Specimen Behaviour and Results	2
Mudstone	3
Sandstone	3
Siltstone	3
Coal	4
CONCLUSIONS	4
REFERENCES	4

TABLES

No.		
1.	Test results	5

FIGURES

1.	Peak and residual strength curves, unit 2c mudstones	20
2.	Peak and residual strength curves, unit 4c mudstones	21
3.	Peak and residual strength curves, unit 5c mudstones	22
4.	Peak and residual strength curves, unit 8c mudstones	23
5.	Peak and residual strength curves, unit 1c sandstones	24
6.	Peak and residual strength curves, unit 5c sandstones	25
7.	Peak and residual strength curves, unit 6c sandstones	26
8.	Peak and residual strength curves, unit 7c sandstones	27
9.	Peak and residual strength curves, unit 8c sandstones	28
10.	Peak and residual strength curves, unit 5c siltstones	29
11.	Peak and residual strength curves, unit 8c siltstones	30

INTRODUCTION

To meet the interactive agreement between the Cape Breton Coal Research Laboratory and the Rock Mechanics Laboratory, a testing program was established to subject several specimens of varying rock types to uniaxial and triaxial compression tests.

The specimens, originating from Borehole SH-93 of the Springhill Coal Mine, Nova Scotia, were tested in January 1984.

The purpose of the tests was to quantify the behaviour of these units for application in new underground mine development.

The multiple failure state test established by Kovari and Tisa (1) was used to extract triaxial information at various confining pressures. Standard uniaxial tests were also performed. Peak strength with accompanying strains, modulus of elasticity, and residual strength data were the parameters required. Both tests were performed using stiff testing equipment to obtain post-failure data.

SPECIMEN DESCRIPTIONS

The samples were obtained from eight lithological units representing four rock types, namely: mudstone, sandstone, siltstone, and coal, Table 1.

On average, the length and diameter of the samples were 8.20 cm and 4.69 cm, respectively. The length to diameter ratio was usually 1.75.

Mudstone samples were obtained from four units. Several samples contained some amount of coal.

Several of the mudstone specimens arrived segmented, due to fissile plane parting. This probably occurred from dessication during transport. After reception the mudstone specimens were maintained moist. After preparation these samples were tested moist, without strain gauges. The samples which contained fissile discontinuities (most samples) were held together with heat-shrink tubing for testing; this tubing was vertically slit for testing. The intact mudstone specimens were tested without tubing. The water content of the mudstone samples during the tests averaged 1.3%.

The sandstones originated from 5 lithological units. The samples contained, to varying degrees, some amount of coal. Most samples were fine-grained; few had grain sizes slightly larger. This rock type was tested dry.

Some specimens of siltstones were tested. These were kept wet because of the unknown content of clay particles (and fissile layers) or gradation within each specimen.

One specimen of coal was tested uniaxially. The sample contained planar weaknesses as well as mineralization and quartz veins.

EXPERIMENTAL SET-UP

A stiff triaxial assembly was used to obtain full pre- and post-failure uniaxial and triaxial response from rock specimens. The confinement to a Hoek pressure vessel was provided by a confining pressure panel capable of generating up to 205 MPa confining pressure [Gorski (2)]. A universal compression testing machine provided the vertical load through a hardened steel cylinder load cell strain gauged to produce micro-strains. Disc springs acted as a stiffening frame to reduce the total energy imparted to the sample by the compression machine. This, and the operation of a magneto-electric valve, which opens and shuts the hydraulic bypass of the testing machine for faster unloading than manual control unloading, permits the resolution of the rock behaviour in the post failure region. This valve was developed by Mr. F. Kapeller of CANMET. Loading was applied at approximately 3×10^{-3} strain/min for all tests. LVDT's were used in conjunction with applied load to trace out the stress-strain curves and to serve as a back up for elastic modulus when the strain gauges were operational. The latter were used also to measure Poisson's ratio, and became a more sensitive indicator of failure onset compared to the LVDT's. On one X-Y-Y pen recorder, two curves were drawn; one with the load cell and LVDT signals yielding a stress-strain curve, one with the load cell and confining pressure signals. On another, the load versus sample deformation using strain gauges (when they can be used) both axially and diametrically. Three strain indicators were used to visually monitor the axial, diametric, and load cell strains during testing.

SPECIMEN BEHAVIOUR AND RESULTS

The low L/D ratios used indicate that reasonable strength results could be higher than those obtained.

Mudstone

Most of the specimens tested contained discontinuities. These samples, therefore, are not representative of intact behaviour.

The failure mode consisted of parting along a number of fissile planes (usually sub-horizontal) and vertical splitting thereby forming a blocky failure mass.

The strength of the specimens was roughly proportional to the pre-test number of discontinuities present in the sample. Intact specimens yielded higher strengths than the samples with one or two discontinuities which, in turn, were stronger than the samples with three or more discontinuities, Fig. 1-4.

Sandstone

Each unit, except 6c, reflects little variation in data, Fig. 5-9. Peak and residual strength values are similar from specimen to specimen. The uniaxial values are a good complement to triaxial envelopes.

Qualitatively arranging the units according to strength, the highest to lowest:

6
7, 8
5
1

The influence provided by the coal is limited to two situations:

- the samples fail along the coal when its outline is <45 degrees to the long axis of the specimen (axial load)
- the coal is arranged in thicknesses >.5 mm thick, or bunched.

Siltstone

Variation in strength exists, Fig. 10-11. Considering the failure modes (planar to vertical splitting), strength could be related to grain size; planar for higher silt content, vertical splitting and fissile splitting for higher clay content.

Coal

Dislocation of weaknesses and failure along intruding veins at low strength values result in high displacement/low modulus of elasticity.

CONCLUSIONS

The four rock types from eight lithological units of the Springhill Coal Mine displayed widely different strength and failure characteristics.

The mudstones of four units, tested moist, failed in a blocky fashion utilizing fissile planes. The strength of the samples was directly related to the amount of discontinuities present in the test specimen.

The sandstones of five units, tested dry, contained coal to varying degrees. Sample failure including this coal depended on the orientation and concentration of coal. Sufficient difference in strength exist to arrange the units in decreasing order of strength (peak and residual); unit 6, 7, 8, 5 and 1.

The strength of the siltstones seem to be dependent on the particle size: low strength for clay-rich specimens, higher strength for clay poor specimens.

The coal specimen failed under low load by dislocating along weaknesses.

REFERENCES

1. Kovari, K. and Tisa, A. "Multiple failure state and strain controlled triaxial tests"; Rock Mechanics 7:17-33; 1975.

2. Gorski, B. "The design and operation of a stiff triaxial assembly for post failure rock property testing; Division Report MRP/MRL 82-81(TR); CANMET, Energy, Mines and Resources Canada; 1982.

Table 1 Test Results

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
60									Not usable
64-A	SST 1 C	1.75	0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	85.9 89.4 93.6 97.5 102.1 107.0 111.3 115.7 124.1	4.3 4.4 4.6 4.7 4.9 5.0 5.2 5.4 6.4	19.3 22.8 25.3 29.6 32.6 34.6 37.5 38.7 40.7			Medium grained SST; planar traces of coal oriented roughly 80° to long axis of specimens; not included in planar failure.
64-B	SST 1 C	1.75	0	111.9	5.8	4.1	28.5+/24.6*	0.17	Medium grained SST; faint traces of coal. Failure mode is planar with vertical splitting.
66-A	SST 1 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	95.5 101.6 105.6 109.7 112.5 114.6 119.8 126.8 132.5 135.3	4.9 5.2 5.3 5.5 5.7 5.8 6.0 6.3 6.7 7.4	8.1 14.2 16.7 20.3 25.4 29.4 32.8 36.5 39.0 43.7			Medium grained SST; faint traces of coal. Failure mode is planar with vertical splitting.
66-B	SST 1 C	1.75	0	66.2	3.6	2.2	22.9+/20.0*	0.23	Medium grained SST; faint planar traces of coal oriented 70° to specimen's long axis; not included in planar failure.

\+ Using strain gauges
* Using LVDT's
SST Sandstone
MST Mudstone
SLT Siltstone

Coal band 0.5mm in thickness
Coal layer 0.5 - 1.0mm in thickness
Coal trace - faintly distinguishable outline of coal.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
67	SST 1 C	1.76	0	87.4	5.2	4.0	20.6+/20.3*		Medium grained SST; faint traces of coal at 60° to long axis of specimen Cemented discontinuity perpendicular to traces. One planar failure, and one failure along cemented discontinuity and part of traces.
81	MST 2 C								unusable
82	MST 2 C								unusable
87	MST 2 C	1.76	0.69	31.2	7.4	12.2			MST with two planar fissile discontinuities present before test. Specimen failure incorporates these and other fissile planes, with vertical splitting between planes. Sample tested moist.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
97-A	MST 2 C	1.76	0.35			10.1			MST with a wavy fissile discontinuity, at end of sample, present before test. Specimen failure is planar with some (fissile planes splitting). Failure is along these planes; failure during 0.69 confinment, giving a lower peak value at the following confinment. Sample tested moist.
			0.69	30.4	7.8	12.6			
			1.03	28.4	8.6	16.6			
			1.38	28.7	9.1	18.7			
			1.72	29.0	9.5	21.1			
			2.07	29.8	10.0	22.3			
			2.41	31.2	10.4	24.7			
			2.76	32.1	11.2	27.0			
			3.10	33.3	11.8	29.6			
			3.45	33.9	12.7	30.8			
97-B	MST 2 C	1.75	0	8.1	16.0	1.75	/1.0*		MST with three planar fissile discontinuities present before test, at 65% to long axis of specimen. Failure along these and other fissle planes; vertical splitting between fissile planes. Sample tested moist, 1.7% water content.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
105	MST 2 C	1.76	0.35			8.1			MST with four pre-test planar fissile discontinuities at 65° to long axis of specimen. Sample tested moist.
			0.69	29.3	10.4	10.6			
			1.03	30.2	11.0	13.4			
			1.38	31.2	11.3	15.6			
			1.72	29.9	11.6	17.9			
			2.07	31.3	11.9	19.9			
			2.41	31.5	12.5	23.3			
			2.76	32.9	13.0	24.0			
			3.10	34.1	13.5	25.6			
			3.45	34.6	14.2	26.8			
113	MST 2 C	1.75	0.35			6.0			MST with three planar fissile discontinuities before test. These were oriented at 70° to the specimens long axis. Sample tested moist.
			0.69	18.3	9.5	8.1			
			1.03	18.9	10.6	10.2			
			1.38	20.7	11.9	12.2			
			1.72	22.8	13.2	13.8			
			2.07	23.9	14.3	16.3			
			2.41	25.2	16.2	18.3			
			2.76	26.0	16.6	19.5			
			3.10	26.8	17.3	20.3			
			3.45	28.4	18.8	22.3			
250	Coal 3 C	1.75	0	8.5	8.6	2.0	/1.7*		Coal, intact specimen. Mineralization on 4 weak planes oriented 40° to the long axis of the specimen. Partly included in failure pattern.
130	MST 4 C								Not usable

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ϵ_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
132	MST 4 C	1.75	0	25.6	8.4	7.7	/5.0*		MST with one curved discontinuity and one planar discontinuity (80° to long axis of specimen) before testing. Sample failed with one vertical split. Sample tested moist,1.3% water content.
162	MST 4 C								Not usable
189	MST 4 C								Not usable
195	MST 4 C	1.74	0	8.2	14.4	4.9	/1.1*		MST with three planar discontinuities, at 80% to the specimen long axis, before testing. These and others in failure pattern along with vertical splitting Sample tested moist, 1.2% water content.
199	MST 4 C								Not usable

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
202	MST 4 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	 34.1 40.2 44.7 40.6 38.2 34.1 33.3 33.7 34.9	 8.3 9.2 10.2 10.2 10.2 10.2 10.2 10.5 11.0	24.4 28.0 30.5 33.3 36.2 37.8 39.0 40.2 41.4			MST with several partially through-going fissile discontinuities before test. These and some faint coal traces are oriented 65% to the specimen's long axis; sample tested moist, 1.1% water content. Sample has broken down after 1.38 MPa confinement.
149	SST 5 C								Not usable
153-A	SST 5 C	1.75	0 0.69	103.1 104.0	6.5 7.6	 18.9	/20.6*		SST with several parallel wavy coal bands. Specimen failure incorporating several such surfaces; vertical splitting also present. Sample tested moist, 1.5% water content.
153-B	SST 5 C	1.75	0.35 0.69 1.03 1.38	 102.8 111.2 120.3	 6.0 6.6 7.2	22.7 27.9 33.0 37.2			SST with several parallel wavy coal bands. Specimen had two planar failures, and a horizontal parting incorporating some coal bands; vertical splitting also present. Sample tested moist, 3.5% water content.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
153-C	SST 5 C	1.75	0	47.9	6.5	5.7	/13.7*		SST with one coal layer running diagonally the full length of the sample, and several wavy traces. Sample failure occurred along the coal layer and perpendicular diagonals. Sample tested moist, 1.3% water content.
171	MST 5 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	 56.1 58.1 60.1 60.9 6 9 66.6 68.3 70.3 70.9	 8.5 8.9 9.2 9.4 9.7 10.1 10.4 10.7 11.0	13.0 17.5 22.2 25.5 29.6 32.8 35.7 37.8 39.4 43.1			MST with two sub-horizontal fissile discontinuities before test. Sample tested moist, 1.2% water content.
172	MST/ SST 5 C	1.75	0	32.1	5.8	15.4	/8.9*		MST with one planar fissile discontinuity before test. Specimen failure mode incorporated this as well as vertical splitting. Sample tested moist, 0.9% water content.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
174	MST/ SST 5 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	 87.4 98.7 96.7 94.7 95.3 94.3 97.1 92.2	 6.8 7.6 7.8 7.9 8.2 8.3 8.6 8.7	 36.2			SLT-MST intact specimen containing faint traces of coal. Failure mode planar with some vertical splitting. Sample cracked after 1.03 MPa confinement.
176-A	MST/ SST 5 C	1.75	0	28.0	7.9	4.1	/5.7*		MST with two fissile discontinuities before test. Sample failure mode along those and vertical splitting. Sample tested moist, 1.3% water content.
176-B	MST/ SST 5 C	1.73	0	59.3	10.2	6.5	/11.8*		MST with several wavy coal traces and one wavy pre-test discontinuity. Failure mode includes these and vertical splitting. Sample tested moist, 1.0% water content.
205-A	SST 6 C	1.75	0	140.0	6.6		22.6+/24.7*		SST, fine grained, with several bunches of wavy coal traces. The latter were in evidence in a curved failure; vertical splitting was also present

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ϵ_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
205-B	SST 6 C	1.75	0	111.9	5.4	4.1	21.9+/23.9*		SST, fine grained, with several planar coal traces at 45° to long axis. Planar failure mode, some splitting along coal traces.
206-A	SST 6 C	1.73	0.35	154.0	3.8				SST, fine grained, several traces of coal. Planar failure mode not containing any of the traces.
			0.69	165.4	4.0	21.9			
			1.03	170.2	4.1	26.8			
			1.38	175.1	4.2	27.6			
			1.72	178.3	4.2	30.1			
			2.07	181.6	4.3	34.1			
			2.41	184.0	4.4	36.6			
			2.76	187.3	4.4	39.8			
			3.10	190.5	4.5	42.3			
			3.45	196.2	4.8	47.9			
210-A	SST 6 C	1.76	0.35			22.4			SST, fine grained, some coal traces. Planar failure and vertical splitting. Sample cracked at peak of 2.07 MPa confinement.
			0.69	240.0	6.8	30.5			
			1.03	250.1	7.2	34.6			
			1.38	260.3	7.5	42.7			
			1.72	264.4	7.7	46.8			
			2.07	266.4	7.9	50.8			
			2.42	248.9	7.9	53.7			
210-B	SST 6 C	1.76	0	218.3	7.3	8.2	41.3+/33.1*	0.16	SST, fine grained, few faint traces of coal. One planar failure and vertical splitting. Sample cracked after 1.38 MPa confinement.
			0.35	226.5	7.6				
			0.69	233.8	7.8				
			1.03	240.0	8.2				
			1.38	242.8	8.3				
			1.72	240.0	8.4				
			2.07	242.0	8.7				

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
210-G	SST 6 C	1.75	0.35 0.69 1.03 1.38 1.72	 226.5 204.5 195.9 199.9	 8.2 8.2 8.2 8.4	20.4 26.5 32.6 38.8 42.8			SST, fine grained. Sample failed with vertical splitting. Sample cracked after 0.69 MPa confinement.
211	SST 6 C	1.75	0	172.7	7.2		37.8+/	0.17	SST, fine grained with several horizontal coal bands. Failure pattern consists of planar failure , vertical splitting and splitting along some of the bands.
212-A	SST 6 C	1.72	0	115.9	6.6		/22.1*		SST, fine grained, with many wavy traces and bands of coal not included in the failure pattern. Planar failure.
212-B	SST 6 C	1.77	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	163.7 171.9 178.6 181.1 181.1	7.5 7.9 8.3 8.5 8.5	16.6 21.6 25.8 29.1 33.2 35.7 39.0 41.5 43.2 44.9			SST, fined grained with several sub-horizontal linear coal traces. Sample failed by vertical splitting.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
239-A	MST/ SST 6 C	1.75	0	191.8	7.1		35.6+/31.2*	0.18	SST fine grained w'th numerous wavy coal bands, not involved in failure pattern. Planar failure and vertical splitting.
239-B	MST/ SST 6 C	1.76	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	234.8 229.2 226.8 227.0 230.0 232.4 238.1 222.7 227.6 238.1	8.0 8.0 8.0 8.0 8.3 8.3 8.4 8.4 8.4 8.6	17.8 26.0 32.5 37.3 43.0 47.1 51.2 55.3 58.5 60.9			SST, fine grained with several planar traces of coal at 45° to long axis of specimen. Planar failure and vertical splitting. Cracking occurred after 0.35 MPA confinement.
251	SLT 7 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	132.8 138.0 140.9 141.8 143.2 144.9 146.8 147.8 150.4 153.5	6.1 6.4 6.6 6.8 6.8 6.9 7.0 7.2 7.3 7.5	20.7 23.6 28.1 32.4 36.4 41.9 45.9 48.3 51.2 53.1			SST, fine grained with several thin coal bands 60° to specimen's long axis. Planar failure not incorporating coal bands.
253	SLT 7 C								Sample not usable.
256-A	SST 7 C	1.75	0	146.4	6.9	6.5	27.0+/24.4*	0.12	SST, faint traces of coal not included in planar failure.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ϵ_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
256-B	SST 7 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	191.5 193.2 193.9 196.4 191.0 185.0 184.7 183.9 128.0 128.4	7.6 7.7 7.8 8.0 8.0 8.0 8.1 8.1 8.3 8.4	21.9 26.1 30.5 34.1 37.4 41.8 44.5 47.5 49.5 51.9			SST, fine grained with faint coal traces not included in planar failure. Cracking of sample after reaching peak at 1.38 MPa confinement. Similar cracking at 2.76 MPa confinement.
256-C	SST 7 C	1.75	0	180.2	6.1		45.0+/34.2*	0.15	SST, fine grained; planar failure and vertical splitting.
256-D	SST 7 C	1.72	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	147.7 152.3 153.0	6.7 7.0 7.1	17.7 22.0 27.2 32.5 35.7 38.2 41.8 44.7 47.1 49.4			SST, fine grained. Unpredictable failure at 1.03 MPa confinement. Planar failure.
257-A	SST 7 C	1.75	0	169.6	7.9		31.7+/27.1*	0.13	SST, fine grained, several coal bands oriented 30° to the specimen's long axis. Planar failure with some splitting along coal bands.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
257-B	SST 7 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	198.8 205.3 209.8 211.1 214.0 218.4 220.9 221.1 222.1 223.7	7.0 7.3 7.4 7.5 7.7 7.8 8.0 8.0 8.1 8.2	17.5 24.0 28.4 34.3 36.4 41.4 44.7 48.9 52.0 54.4			SST, fine traces of coal at 45° to the specimen's long axis. Planar failure pattern, vertical splitting, not incorporating coal traces.
261	SLT 7 C								Sample not usable.
286	SST/ MST 8 C	1.75	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	 68.0 74.8 80.8 103.1 101.0 101.9 98.7 95.9 93.0		10.6 15.2 19.2 23.8 27.3 30.8 34.4 36.9 39.9 42.5			MST, intact, with one wavy coal band. Failure mainly by vertical splitting, and partially along coal band. Sample tested moist, 1% water content. Cracking at 1.72 MPa confinement.
286-A	SST/ MST 8 C	1.75	0	177.2	8.6		30.0+/26.4*	0.14	SLT, with faint wavy coal traces not included in planar failure.
286-B	SST/ MST 8 C	1.72	0.35 0.69 1.03 1.38 1.72 2.07 2.41 2.76 3.10 3.45	200.8 204.9 203.7 207.3 206.7 209.3 212.2 196.7 162.2 172.8	7.2 7.5 7.6 7.8 7.9 8.0 8.2 8.2 8.2 8.4	15.0 21.1 24.8 28.9 32.5 37.0 40.2 43.9 47.2 48.6			SLT, no coal, planar failure. Cracking at 2.41 MPa confinement.

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
288-A	MST 8 C	1.75	0	25.7	8.0	3.7	/15.5*		MST, with one fissle discontinuity 80° to specimen's long axis. Failure along several fissile planes, intersected by vertical splits. Sample tested moist, 0.7% water content.
288-B	MST 8 C	1.75	0.35			10.6			MST, sample intact. Failure pattern along several fissile planes intersected by vertical splits. Cracking after 1.03 MPa confinement. Sample tested moist, 1.3% water content.
			0.69	79.8	8.9	14.2			
			1.03	83.3	9.1	18.3			
			1.38	77.6	9.1	21.1			
			1.72	74.4	9.3	24.4			
			2.07	76.8	9.6	26.8			
			2.41	78.6	10.0	30.1			
			2.76	78.8	10.2	32.1			
			3.10	78.7	10.3	34.9			
			3.45	72.3	10.4	36.6			
291-A	MST/ SST 8 C	1.76	0.69	43.9	3.5				SLT-MST, intact with some wavy coal bands. Failure pattern defined partly by vertical splitting. Sample tested moist, 0.8% water content. Cracking after 2.76 MPa confinement.
			1.03	50.0	4.0				
			1.38	57.7	4.9				
			1.72	57.5	5.0				
			2.07	59.3	5.4				
			2.41	60.2	5.5				
			2.76	61.0	6.1				
			3.10	58.9	6.1				
			3.45	55.3	7.0	35.8			

Table 1 Test Results (cont)

Sample No	Lith. Unit	L/D	σ_3(MPa)	σ_{1p}(MPa)	ε_p(x10^{-3})	σ_r(MPa)	E(GPa)	ν	Remarks
291-B	SST 8 C	1.75	0.35			7.7			MST, intact specimen with one partially discontinuous fissile plane. Planar failure accompanied by some fissile planes. Sample tested moist, 1.2% water content. Cracking after 2.76 MPa confinement.
			0.69	22.4	10.3	10.2			
			1.03	23.0	10.6	12.4			
			1.38	24.4	10.9	15.0			
			1.72	26.0	11.4	17.5			
			2.07	26.8	11.6	19.1			
			2.41	28.0	12.0	21.2			
			2.76	28.9	12.5	23.2			
			3.10	26.9	12.5	24.0			
			3.45	25.2	12.5	24.4			
292	SST 8 C	1.73	0.35	157.4	4.5	18.7			SST, fine grained, with several faint coal traces at 70° to the specimen's long axis. Planar failure pattern with some splitting occurring along the coal traces. Cracking after 1.38 MPa confinement.
			0.69.	212.6	5.3	24.3			
			1.03	221.5	5.4	29.6			
			1.38	222.3	5.5	34.1			
			1.72	220.6	5.5	37.7			
			2.07	228.8	5.5	42.2			
			2.41	231.2	5.6	47.1			
			2.76	213.4	5.6	49.5			
			3.10	211.7	5.7	51.9			
			3.45	214.2	5.7	55.2			
294	SST								Unusable.

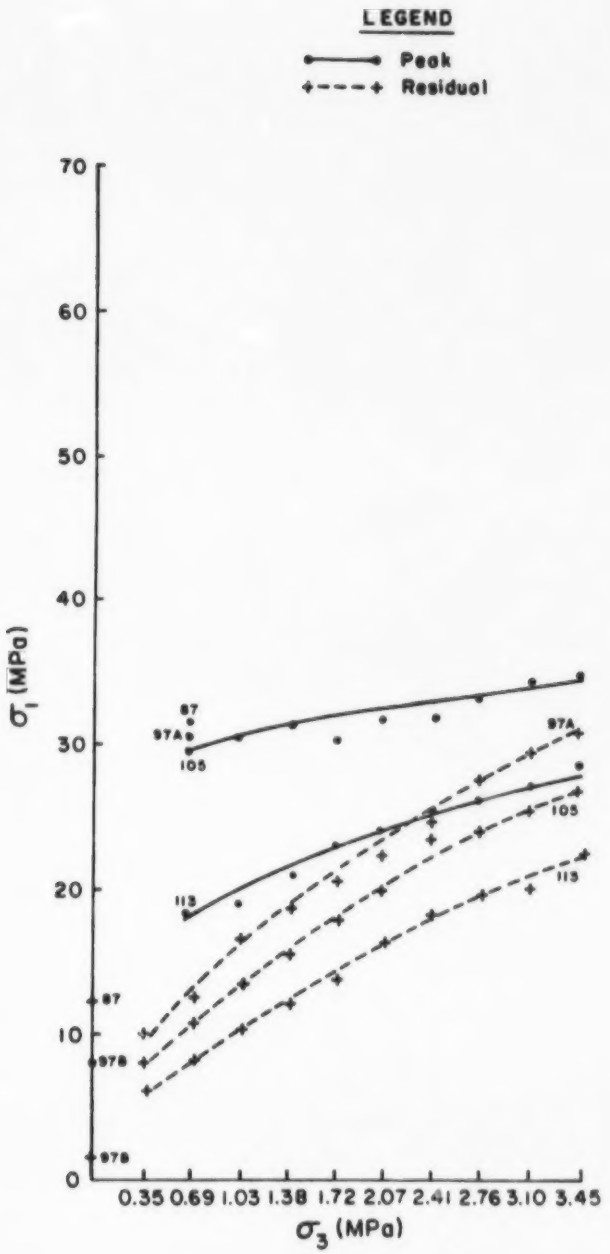

Fig. 1 - Peak and residual strength curves, unit 2c mudstones

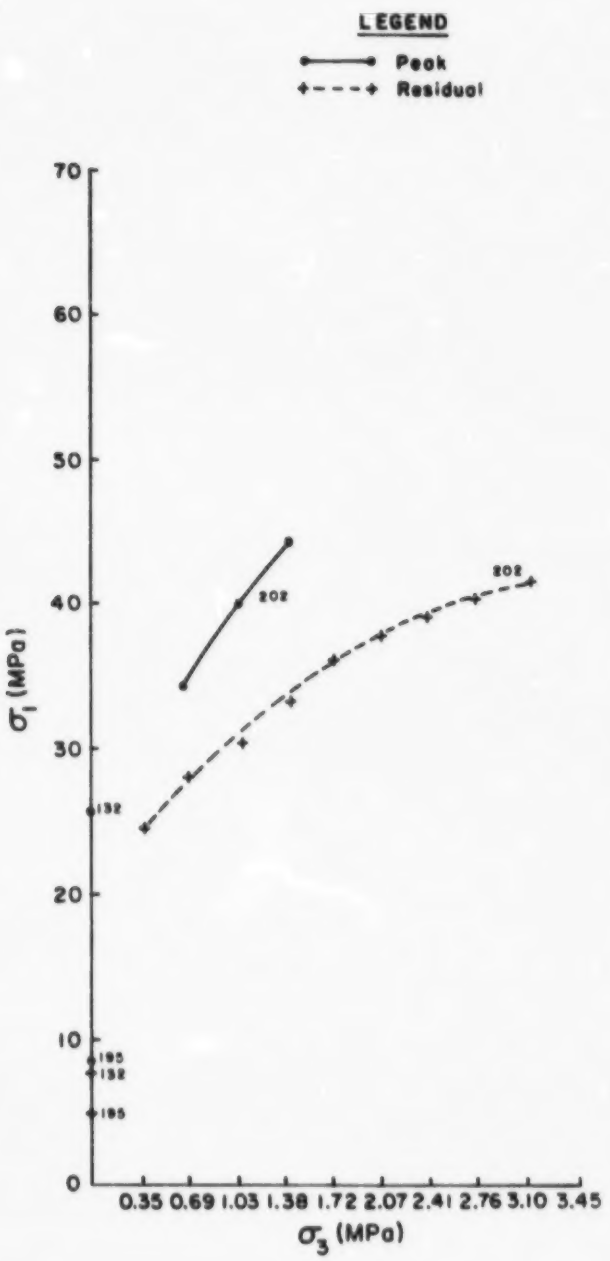

Fig. 2 - Peak and residual strength curves, unit 4c mudstones

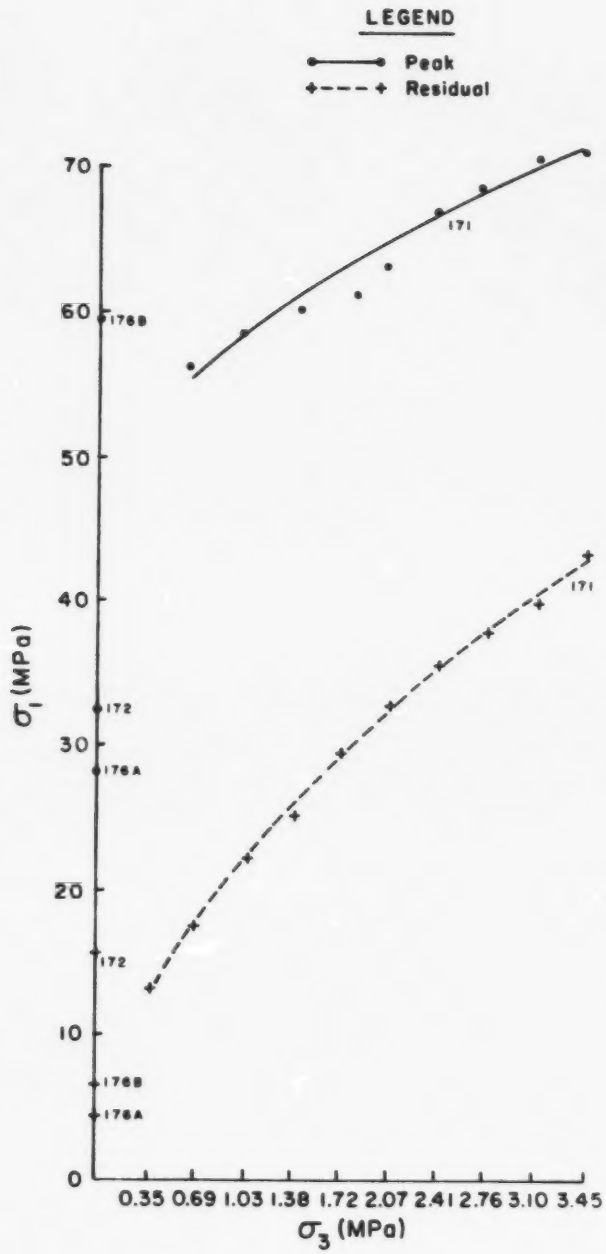

Fig. 3 - Peak and residual strength curves, unit 5c mudstones

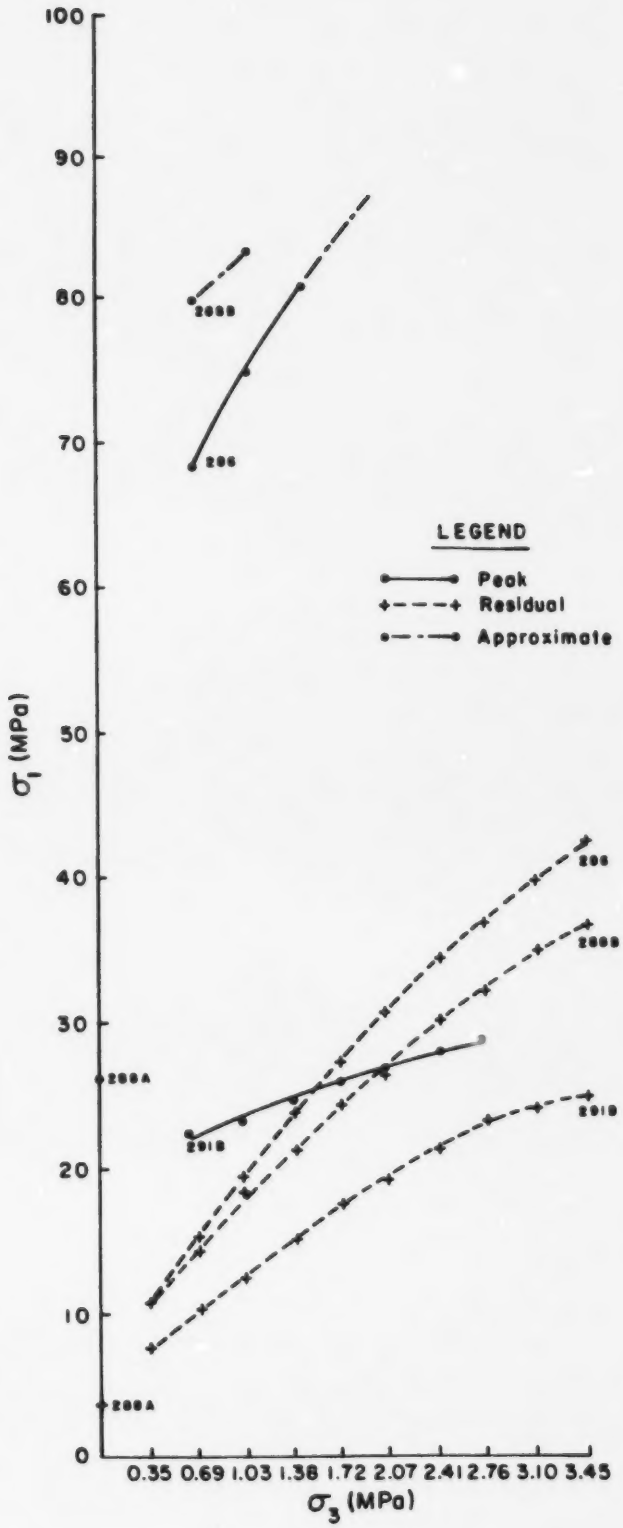

Fig. 4 - Peak and residual strength curves, unit 8c mudstones

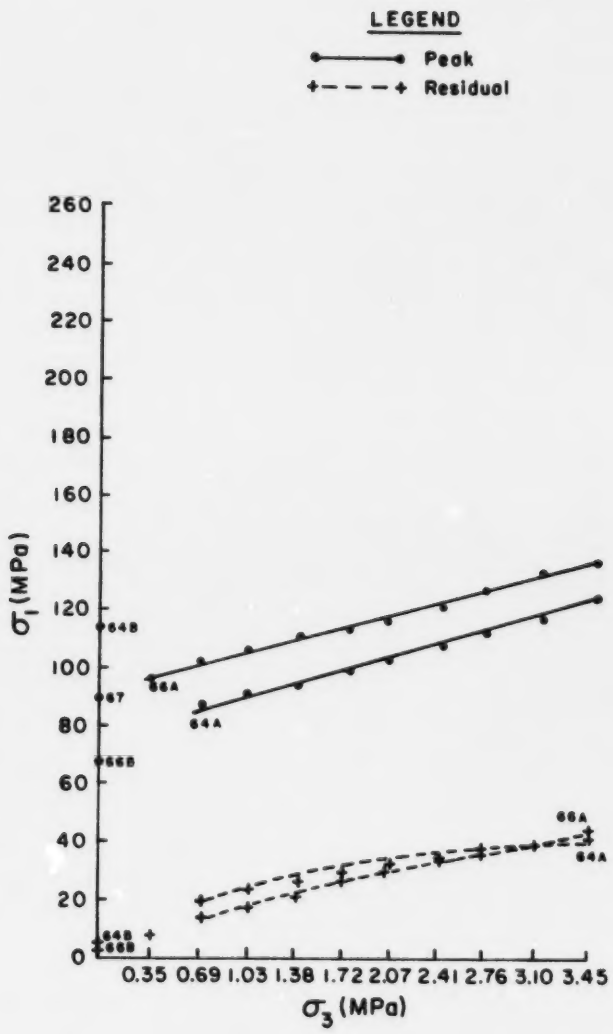

Fig. 5 - Peak and residual strength curves, unit 1c sandstones

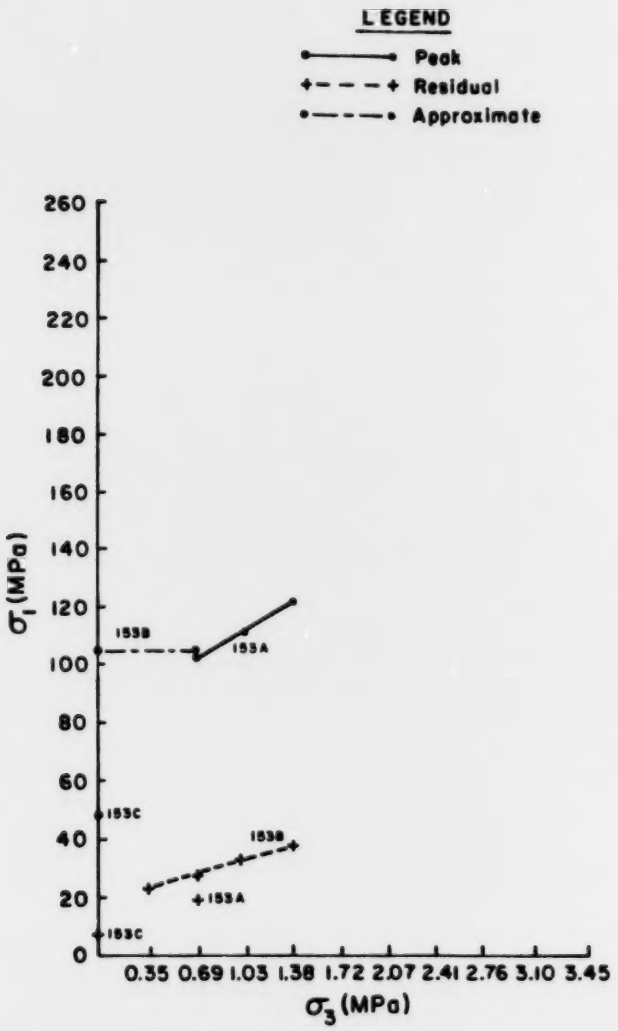

Fig. 6 - Peak and residual strength curves, unit 5c sandstones

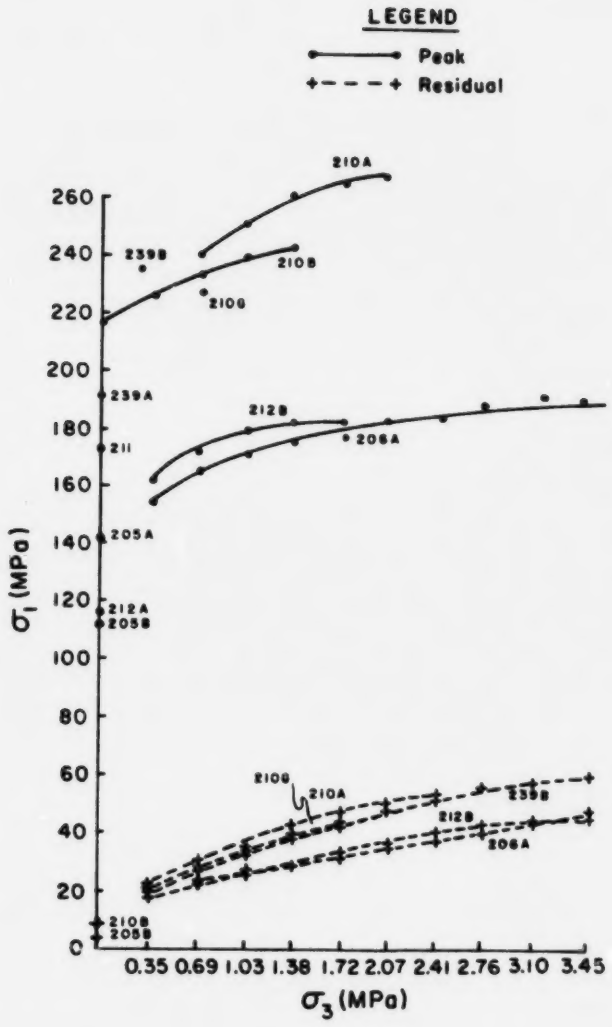

Fig. 7 - Peak and residual strength curves, unit 6c sandstones

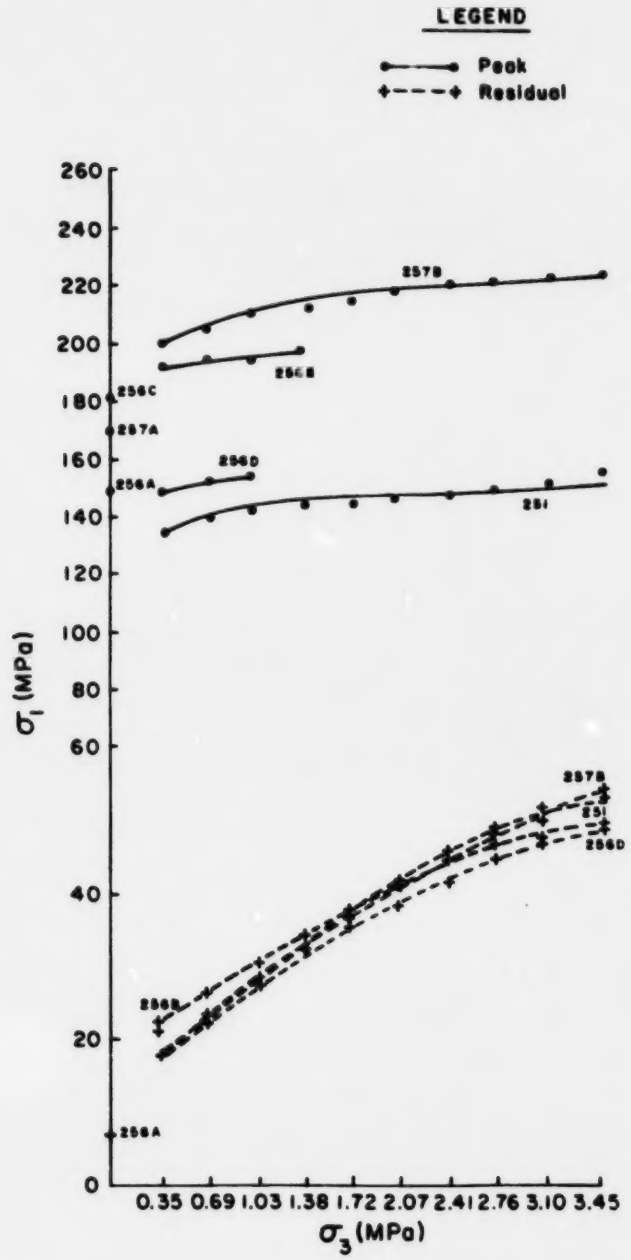

Fig. 8 - Peak and residual strength curves, unit 7c sandstones

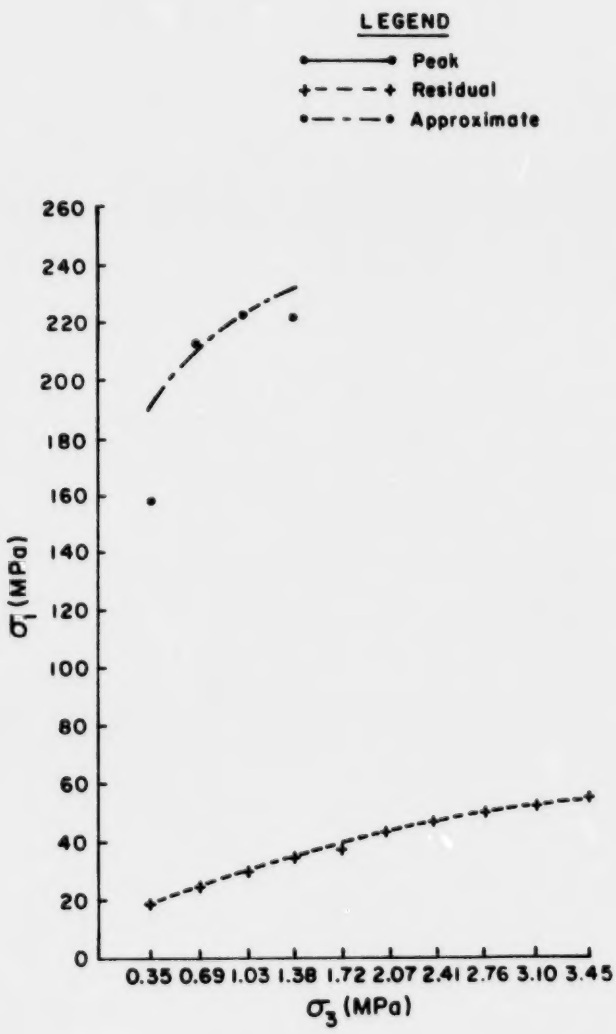

Fig. 9 - Peak and residual strength curves, unit 8c sandstones

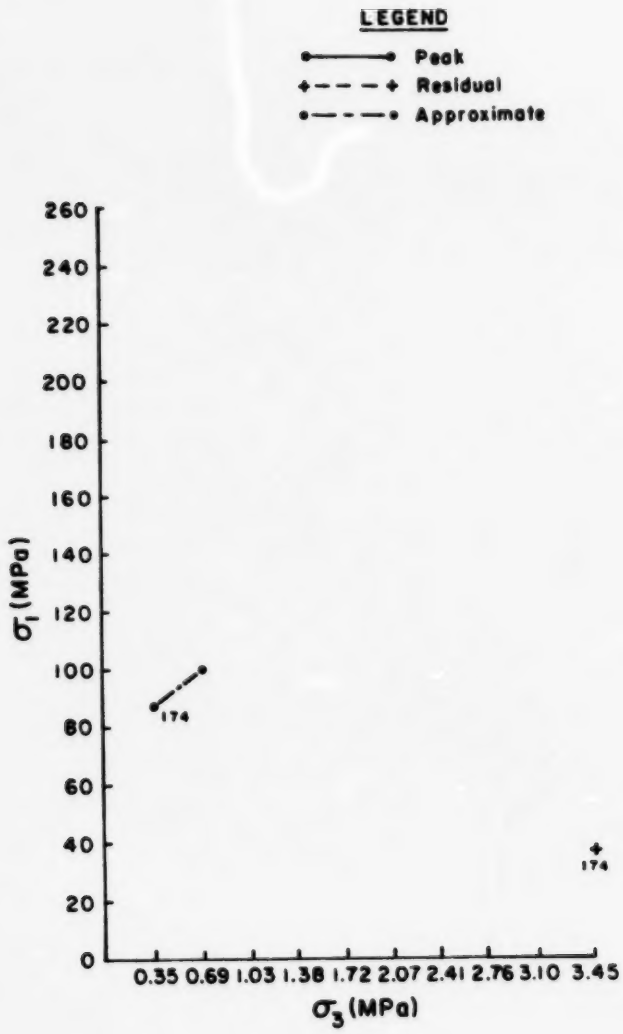

Fig. 10 - Peak and residual strength curves, unit 5c siltstones

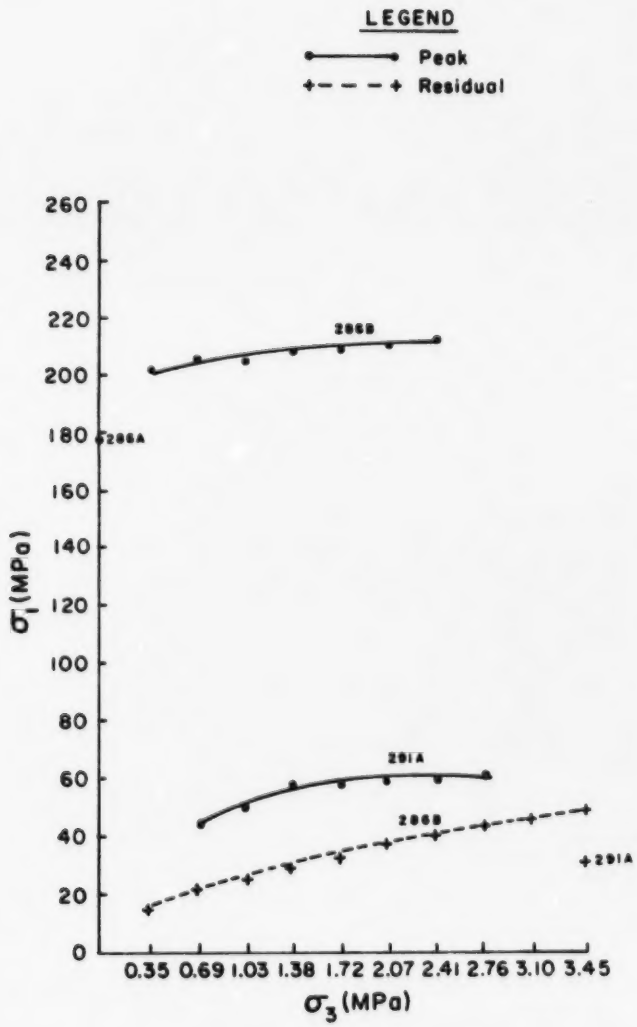

Fig. 11 - Peak and residual strength curves, unit 8c siltstones

POOR

QUALITY

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